Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)

Submission Title: [Harmonization of The 15.4g Mandatory Data Rate Proposal]
Date Submitted: [17 March, 2010]

Source: [Khanh Tuan Le] Company [Texas Instruments]
[] Company []
Address [Gaustadalleen 21, 0349 Oslo, Norway]
Voice: [+47 22958535], E-Mail:[k.t.le@ti.com]

Re: []

Abstract: [Proposal to use 2-GFSK BT=0.5 for 15.4g 50 kbps mandatory data rate. Background and elaboration.]

Purpose: [Technical proposal. Presented to the 802.15.4g SUN Task Group for consideration.]

Harmonization of The 15.4g Mandatory Data Rate Proposal

17th March 2010

Khanh Tuan Le

Background

- Ref.: 15-10-0031-03-004g-candidate-text-comments.xls
  Comment #324:
  "The mandatory data rate 50 kbps at the 915 MHz ISM band is specified using FSK while the same mandatory data rate at all other ISM bands is specified using GFSK.
  Spectrum efficiency and low adjacent channel power are desirable and hence GFSK is a better choice than FSK."

- **Proposed Change**:
  "Recommend to change from FSK to GFSK with BT=0.5. The definition of the mandatory data rate 50 kbps will be unified across all listed ISM bands.“

- **Advantages**:
  Harmonization of the 50 kbps mandatory data rate using GFSK modulation format for **improved spectrum efficiency and better co-existence *without* any performance, cost or power trade-offs**.

Intention of The Proposed Change

- GFSK is a better modulation format choice than FSK for the IEEE 802.15.4g mandatory data rate of 50 kbps at the ISM frequency bands based on technical performance merits.
- There are no technical reasons to differentiate the modulation format of the mandatory data rate for various ISM frequency bands.
- As specifically stated in comment #324, the proposal relates only to the IEEE 802.15.4g mandatory data rate of 50 kbps at the ISM frequency bands and not the optional data rates with various modulation definitions.

AGENDA

- 15.4g Mandatory Data Rate
- GFSK In A Nutshell
- RF Link Performance
- Spectrum Efficiency and Co-Existence
- GFSK Radio Availability and Maturity
- Conclusions

15.4g Mandatory Data Rate at ISM Bands

Frequency band (MHz)	Parameter	Mandatory data rate
470–510 (China)	Data rate (kb/s)	50
	Modulation	GFSK
	Modulation index	1.0
	Channel spacing (kHz)*	200
863–870 (Europe)	Data rate (kb/s)	50
	Modulation	GFSK
	Modulation index	1.0
	Channel spacing (kHz)	200
902–928 (ISM) 2400–2483.5 (Worldwide)	Data rate (kb/s)	50
	Modulation	FSK
	Modulation index	1.0
	Channel spacing (kHz)	200
TBD: Dedicated use bands	TBD	TBD

Frequency band (MHz)	Parameter	Mandatory data rate #1
400–430 (Japan) 950.1–955.7 (Japan)	Data rate (kb/s)	50
	Modulation	GFSK
	Modulation index	1.0
	Channel spacing (kHz)* †	200/400

IEEE P802.15-10-0014-00-004g

(January, 2010)

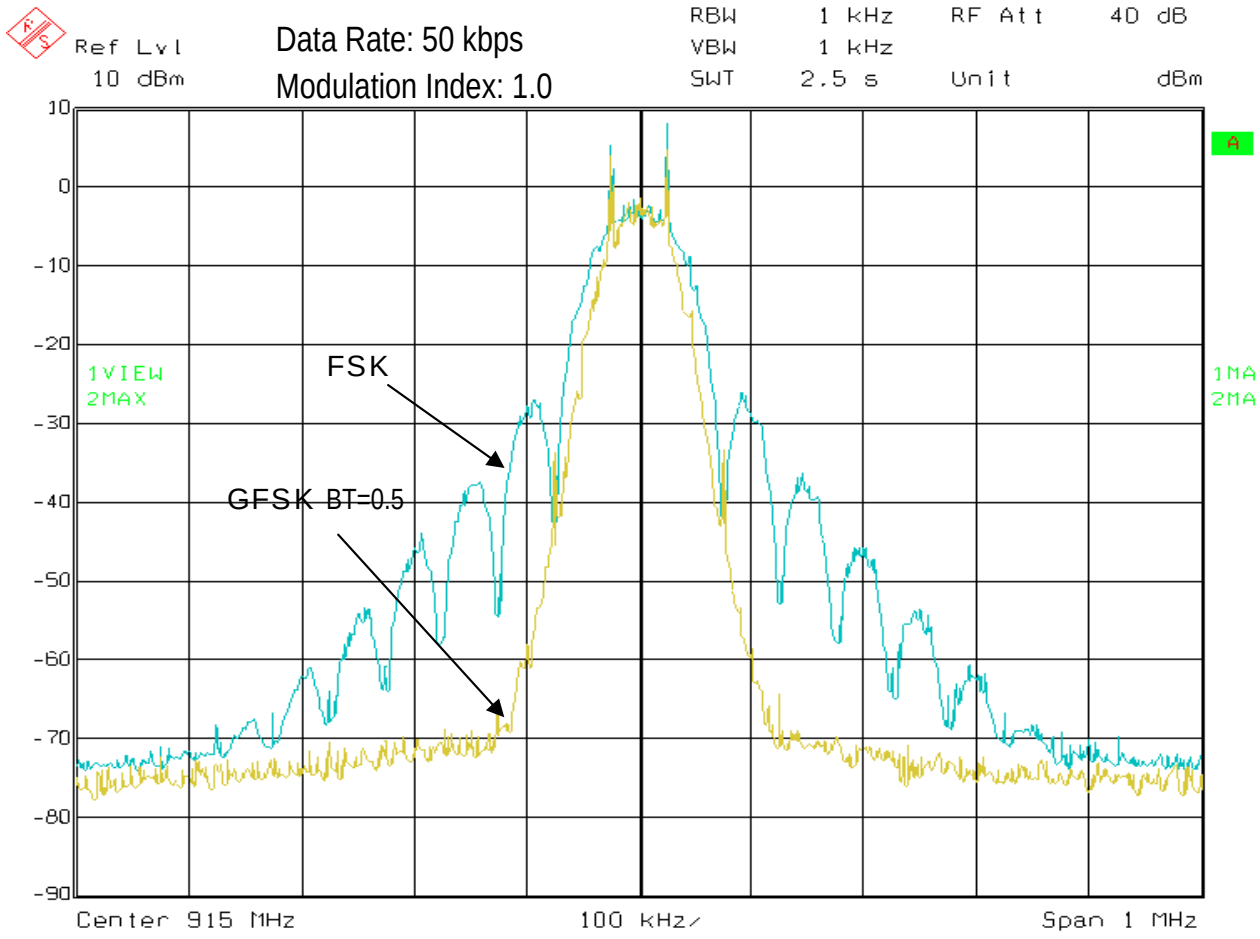
- Data Rate: 50 kbps - Harmonized.
- Modulation Index: 1.0 - Harmonized.
- Channel Spacing: 200 kHz - Harmonized.
- Are there any *technical reasons* to differentiate the modulation format of the mandatory data rate for different frequency bands?

GFSK In A Nutshell (1)

- Gaussian Frequency-Shift Keying (GFSK) is an spectrally enhanced version of FSK.
  - FSK is a relative spectrum inefficient modulation type. A better spectrum efficiency of FSK is established when data is passed through a Gaussian filter before modulation. The use of the Gaussian filter prevents the instantaneous changes in frequency inherent in FSK. This results in a power spectrum with side lobes having energy levels far lower than those of a FSK power spectrum.
- Gaussian shaping, typically done in the digital domain, provides a proven, widely used and accurate technique to limit adjacent channel interference to coexisting wireless systems.
- GFSK has been utilized in many IEEE standards, including IEEE 802.15.1 (Bluetooth) and IEEE 802.15.4d (ratified in 2009, newest 15.4 PHY amendment).
- All submitted 15.4g proposals include GFSK.

GFSK In A Nutshell (2)

- GFSK concentrates more power in the main lobe.
- GFSK has significantly lower interfering power leakage into neighboring channels.



RF Link Performance

- Transmitter: GFSK and FSK are both constant envelope modulation techniques and can use exactly the same non-linear power-efficient transmitter architectures and circuit designs.
- Receiver:
  - GFSK and FSK based radios will satisfy the receive sensitivity requirement for the 50 kbps mandatory data rate specified by the IEEE 802.15.4g (draft: -90 dBm).
  - GFSK and FSK with modulation index 1.0 provide the same receive sensitivity without any cost or power differences.

✓ **GFSK and FSK provide the same RF link performance.**

Ref.: IEEE 802.15-10-0137-00-004g

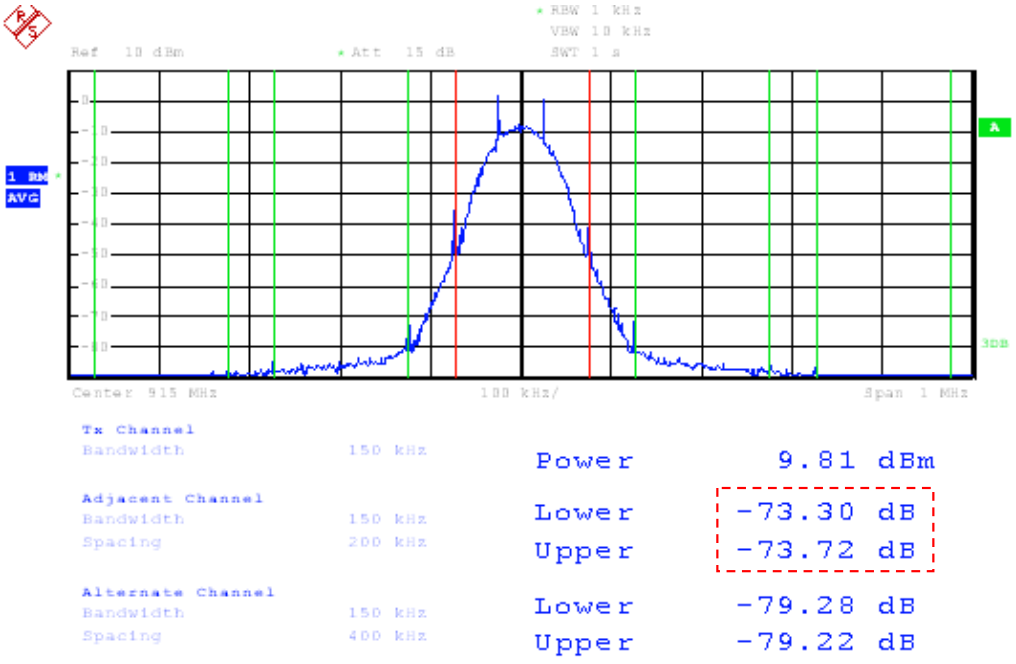
Datarate = 50kbps Measured Data in the ISM Band 902-928MHz

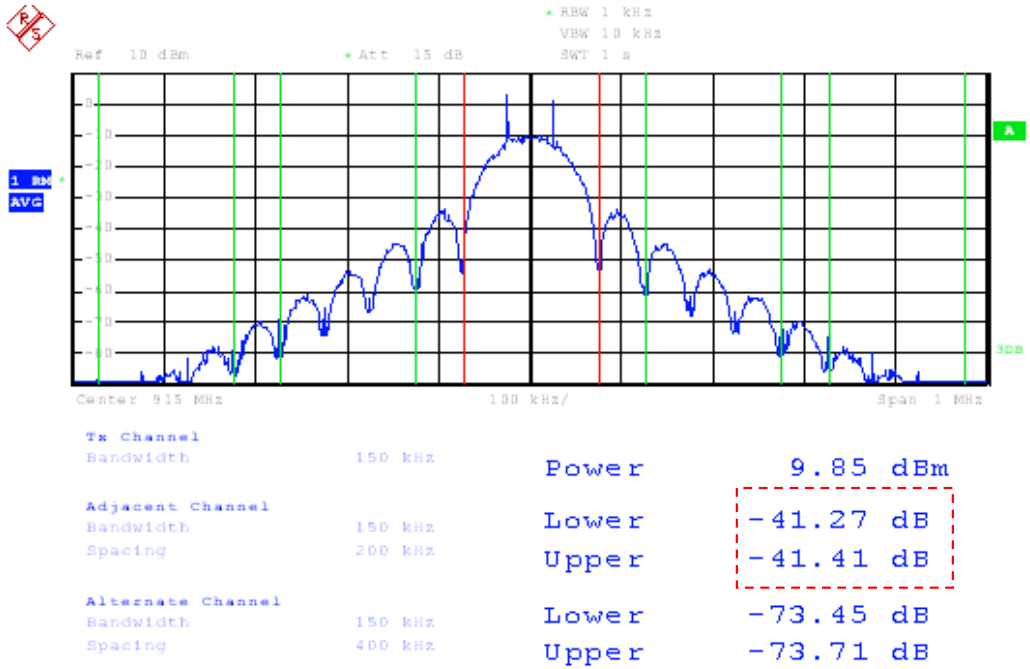
Modulation	Mod Index	IF bandwidth	Sensitivity (dBm)
FSK	1	100kHz	-107.2
GFSK	1	100kHz	-107.4
FSK	1	150kHz	-107.2
GFSK	1	150kHz	-107

Spectrum Efficiency and Co-Existence

- ISM bands are unlicensed frequency bands
  - Co-existence with 15.4g and also other radio devices is important.
- Large and rapidly increasing number of deployed devices
  - Focus on co-existence is and will be increasingly important.
- Co-existence in terms of modulation spectrum efficiency must be addressed at the PHY level.
- Co-existence and efficient spectrum utilization are not only a regulatory issue.

GFSK Has The Best Spectrum Efficiency



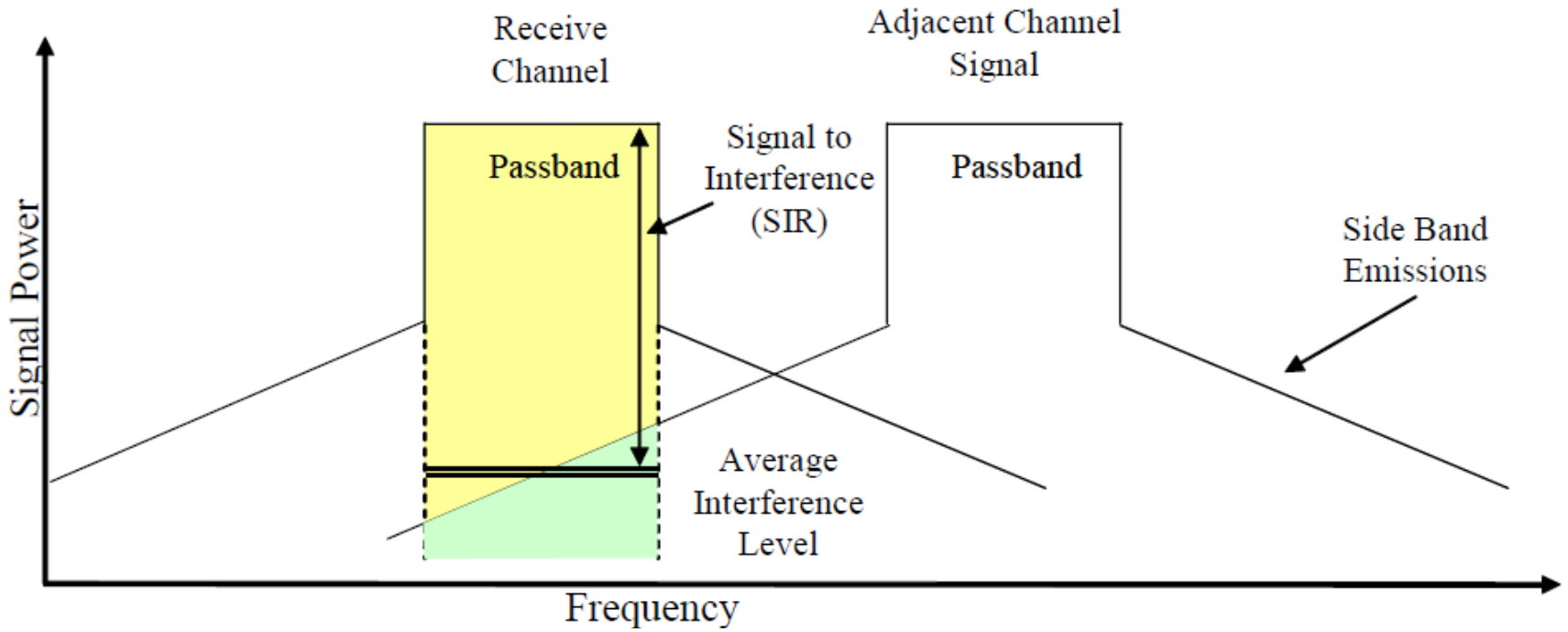


- GFSK has significantly less (>30 dB better) power leakage into neighboring channels than FSK.
- 99% occupied bandwidth: GFSK 25% more compact than FSK.

✓ **GFSK is inherently more spectrally efficient than FSK.**

✓ **GFSK is better than FSK in terms of co-existence.**

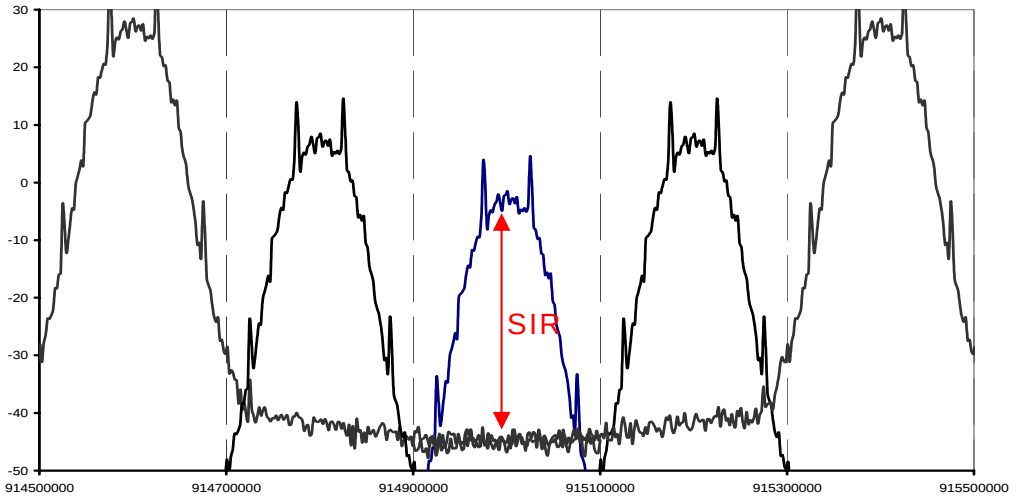
Adjacent Channel Interference (ACI)



- Escalating deployment of wireless technology in the unlicensed ISM frequency bands
- Large number of radios operating in the same frequency bands
- Interference problem

Spectrum Utilization and ACI

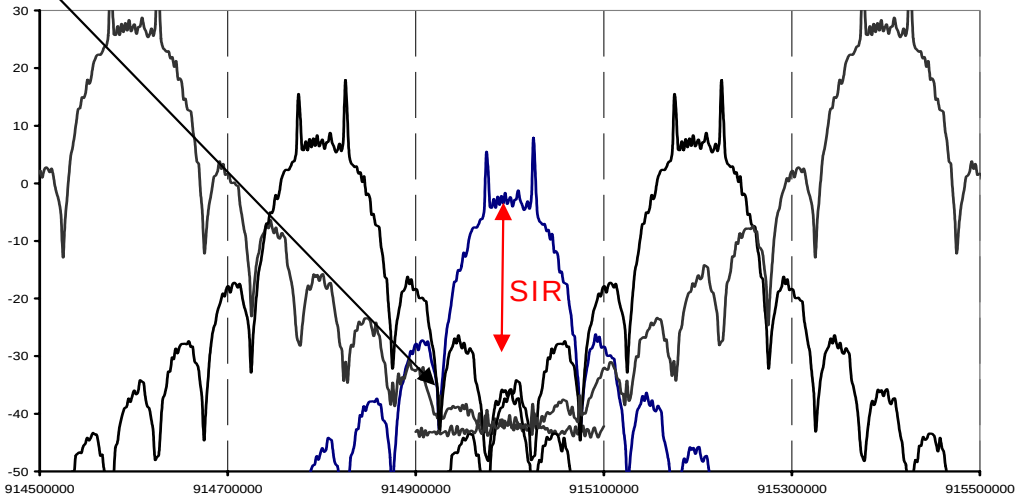
Data Rate: 50 kbps
Modulation Index: 1.0
2-GFSK BT=0.5
Channel Spacing: 200 kHz



Unwanted signal power leaked into neighboring channels can result in:

- Reduced system performance
- More demanding Adjacent Channel Rejection (ACR) requirements, i.e. higher complexity and more power hungry radios (more signal power and signal processing required for the same SIR)

Data Rate: 50 kbps
Modulation Index: 1.0
2-FSK
Channel Spacing: 200 kHz



GFSK Radio Availability and Maturity (1)

- Simple, low-cost and low-power GFSK radios are readily available.
- Off-the-shelf radio transceivers today support both GFSK and FSK without any cost or power penalties.
- GFSK radios are highly flexible (programmable) and can effectively support the 15.4g mandatory data rate and optional data rates.
- GFSK has been widely used for AMR/AMI applications, including ultra-low power metering systems.

GFSK Radio Availability and Maturity (2)

- New standards seem to favor GFSK, not FSK, for better utilization of the spectrum.
- IEEE GFSK-based standards
  - IEEE 802.11b (WLAN)
  - IEEE 802.15.1 (Bluetooth)
  - IEEE 802.15.4d - ratified in 2009, newest 15.4 PHY amendment
- All submitted 15.4g proposals include GFSK
  - GFSK is considered as a proven and more future-proof technology than FSK.
- *Do you know of any recent IEEE standards based on FSK?*

15.4g Participants' Statements About GFSK

- **Ref. 15-09-0490-00-004g, John Buffington (Itron) and Bob Mason (Elster)**

  GFSK Advantages

  – Lower adjacent channel emission than FSK complying to local regulations
  – Low complexity in the modem serving low cost endpoints
  – Proven technology for FHSS regulations
  – Proven technology for Meter reading

GFSK In The 15.4g Draft

Frequency band (MHz)	Parameter	Mandatory data rate	Optional data rate #1	Optional data rate #2
450–470 (FCC Part 22/90)	Data rate (kb/s)	5	10	20
	Modulation*	GFSK	GFSK	GFSK
	Modulation index	0.5	0.5	0.5
	First Channel Frequency	*BandEdge* + 31.25 kHz	*BandEdge* + 37.5 kHz	*BandEdge* + 50 kHz
	Channel spacing (kHz)	12.5	25	50
470–510 (China)	Data rate (kb/s)	50	100	200
	Modulation*	GFSK	GFSK	4-GFSK
	Modulation index	1.0	1.0	1/3
	First Channel Frequency	*BandEdge* + 300 kHz	*BandEdge* + 400 kHz	*BandEdge* + 400 kHz
	Channel spacing (kHz)†	200	400	400

Frequency band (MHz)	Parameter	Mandatory data rate #1	Mandatory data rate #2	Optional data rate
400–430 (Japan) 950.1–955.7 (Japan)	Data rate (kb/s)	50	100	200/400
	Modulation*	GFSK	GFSK	GFSK/4-GFSK
	Modulation index	1.0	1.0	1.0/0.33
	Channel spacing (kHz)†‡	200/400	400	600

863–870 (Europe)	Data rate (kb/s)	50	100	200
	Modulation*	GFSK	GFSK	4-GFSK
	Modulation index	1.0	1.0	1/3
	First Channel Frequency	*BandEdge* + 300 kHz	*BandEdge* + 400 kHz	*BandEdge* + 400 kHz
	Channel spacing (kHz)	200	400	400
902–928 (ISM) 2400–2483.5 (Worldwide)	Data rate (kb/s)	50	150	200
	Modulation*	FSK	FSK	GFSK
	Modulation index	1.0	0.5	0.5
	First Channel Frequency	*BandEdge* + 300 kHz	*BandEdge* + 400 kHz	*BandEdge* + 400 kHz
	Channel spacing (kHz)	200	400	400
869 (EU G3) 896–901 (FCC Part 90) 901–902 (FCC Part 24) 928–960‡ (FCC Part 22/24/90/101) 1427–1518‡ (US FCC Part 90)/ (Canada SRSP 301.4)	Data rate (kb/s)	10	20	40
	Modulation*	GFSK	GFSK	GFSK
	Modulation index	0.5	0.5	0.5
	First Channel Frequency	*BandEdge* + 62.5 kHz	*BandEdge* + 75 kHz	*BandEdge* + 100 kHz
	Channel spacing (kHz)	25	50	100

Reference: IEEE P802.15-10-0165-00 (March, 2010)

Proposed Change Summary

	GFSK	FSK
Proven In The Field	Yes	Yes
Good Sensitivity	Yes	Yes
Power Efficient Transmitters	Yes	Yes
Excellent Range	Yes	Yes
Low Complexity & Low Power	Yes	Yes
Availability	Yes	Yes
Spectrum Efficient and Co-Existence Friendly	Yes	
Utilized in Recent IEEE Standards	Yes	
Harmonization of The Mandatory Data Rate	Yes	
Conclusion: GFSK is the best technical choice for the harmonized 15.4g mandatory data rate without any performance, cost or power compromises!		

Conclusions

- GFSK is inherently better than FSK in terms of co-existence because GFSK causes significantly less Adjacent Channel Interference than FSK.
- GFSK provides the same RF link performance as FSK.
- There are no technical reasons to differentiate the modulation format of the mandatory data rate for different ISM frequency bands.
- Harmonization of the mandatory data rate for best overall system performance can be achieved by choosing GFSK as the modulation format.

Thank you!